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ANALYSIS OF HYDROPOWER IMPACT IN WATER ENERGY NEXUS FOR SMART ENERGY SYSTEMS

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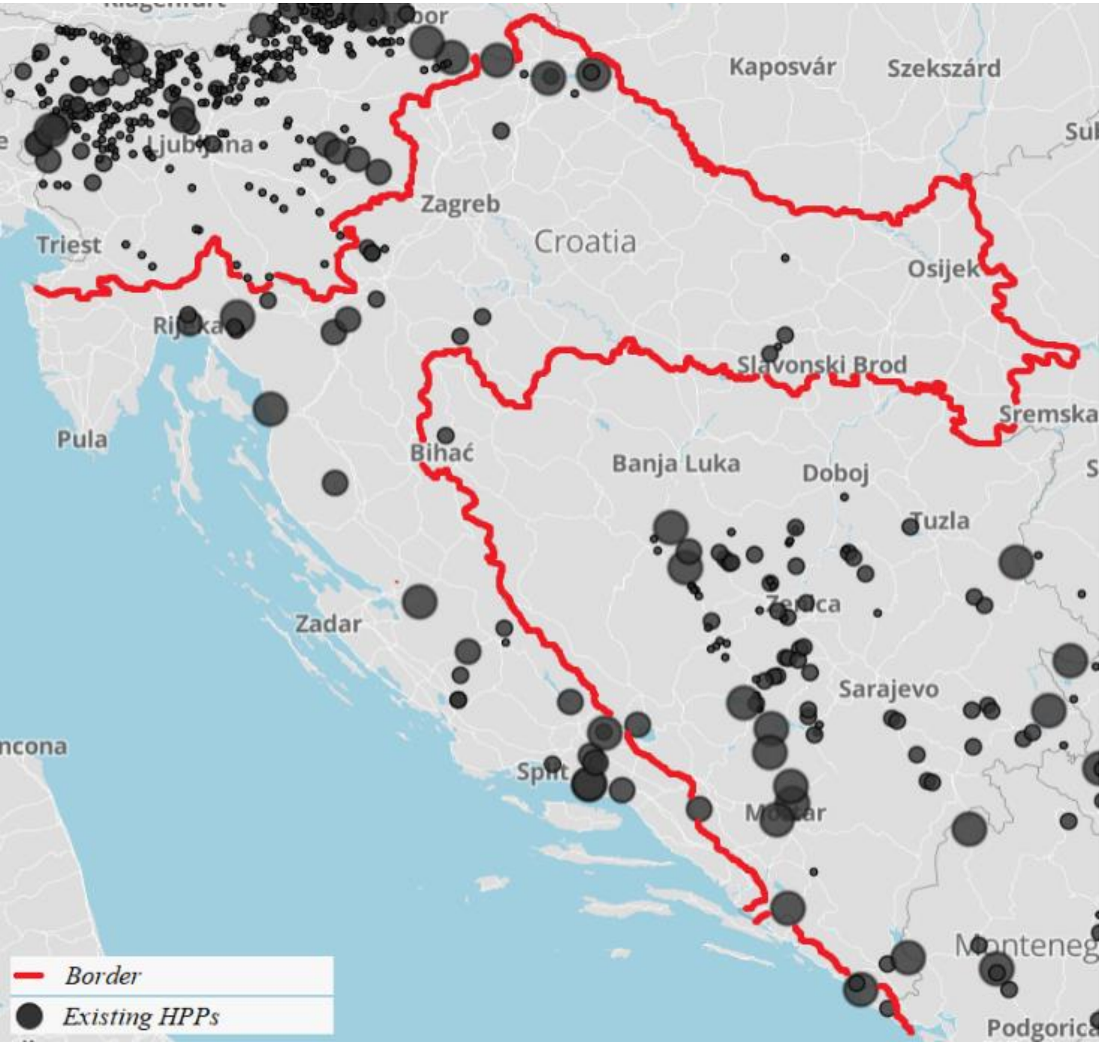
1. Studied region
2. Water-power (water-energy) nexus
3. LISFLOOD rainfall-runoff hydrological model
4. Energy model
5. Results

Studied region

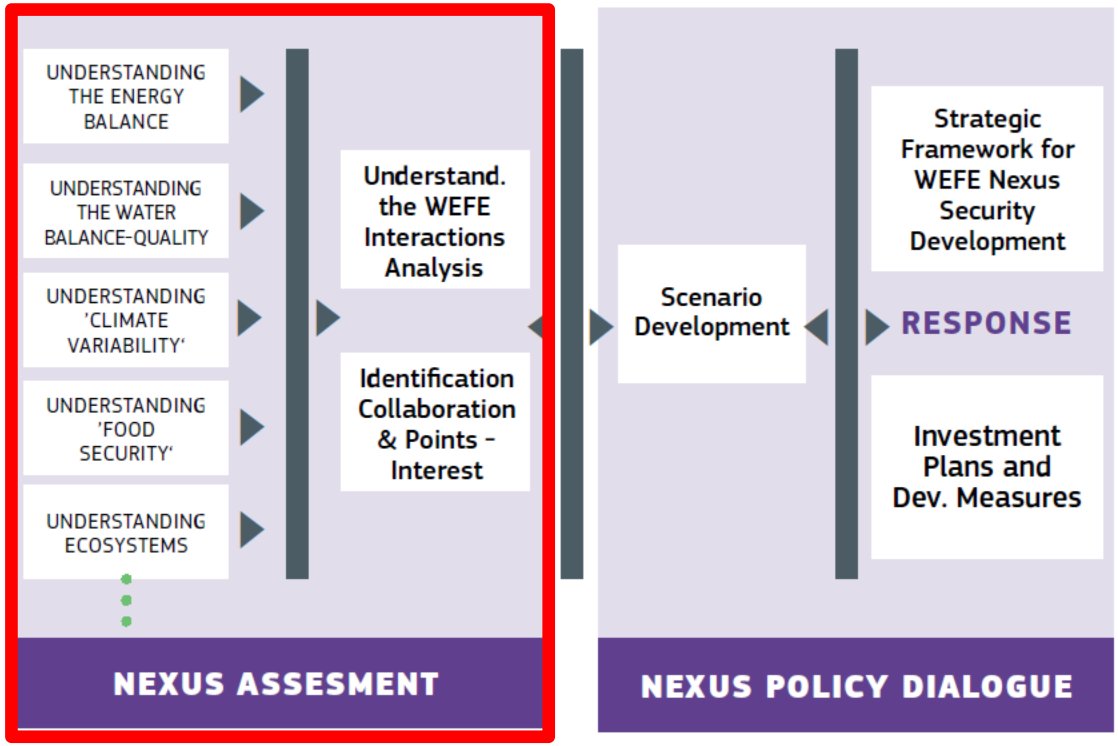


Type of hydropower	Power capacity
Run-of-river	405 MW
Accumulation hydropower	1486 MW
Pumped hydropower	275 MW
Small hydropower	33 MW

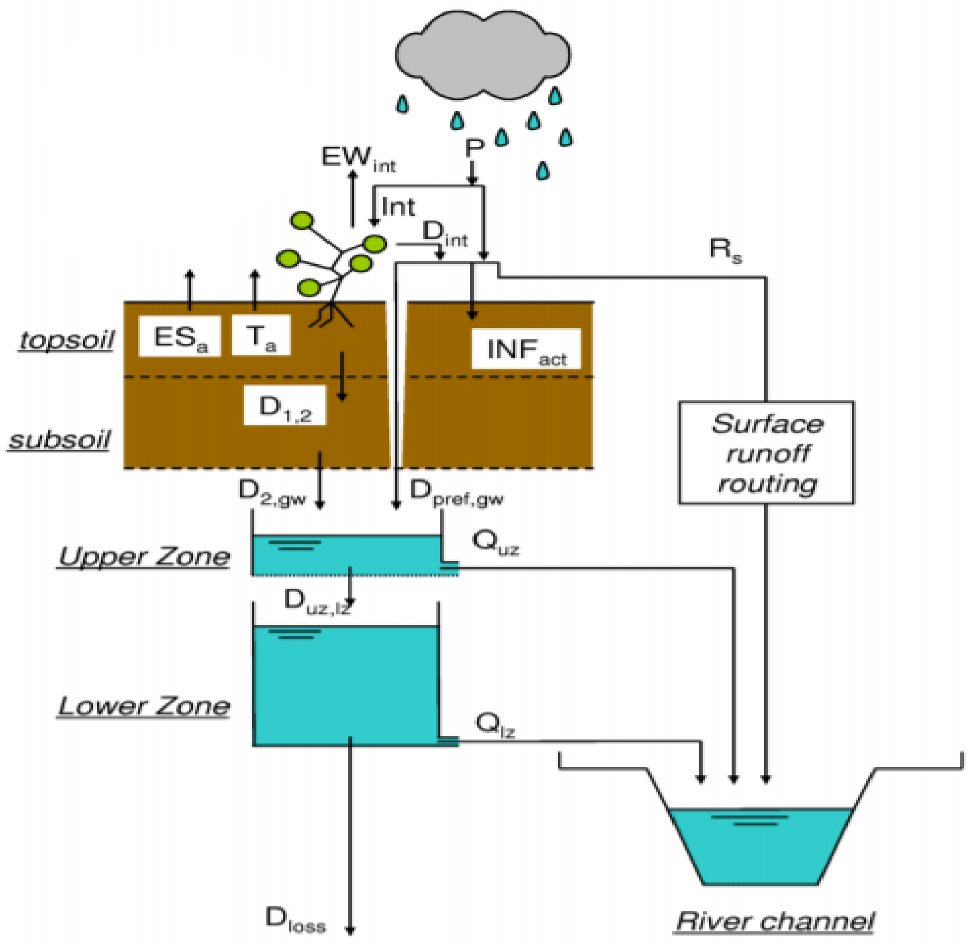
Future capacities	
Revitalization in 10 years	45 MW
New capacities in 20 years	1725 MW
New capacities in 3 years	206 MW

Water-energy nexus

- Power generation sector worldwide accounts for high water withdrawal and consumption
- Water resources are also used for purposes of irrigation, flood control, water supply, agriculture etc.
- Impacts on the power system due to the climate change, raise the questions on how to implement better water management
- The term **water-energy** nexus is used to refer the interactions between the water and energy sectors for the optimal utilization of water resources

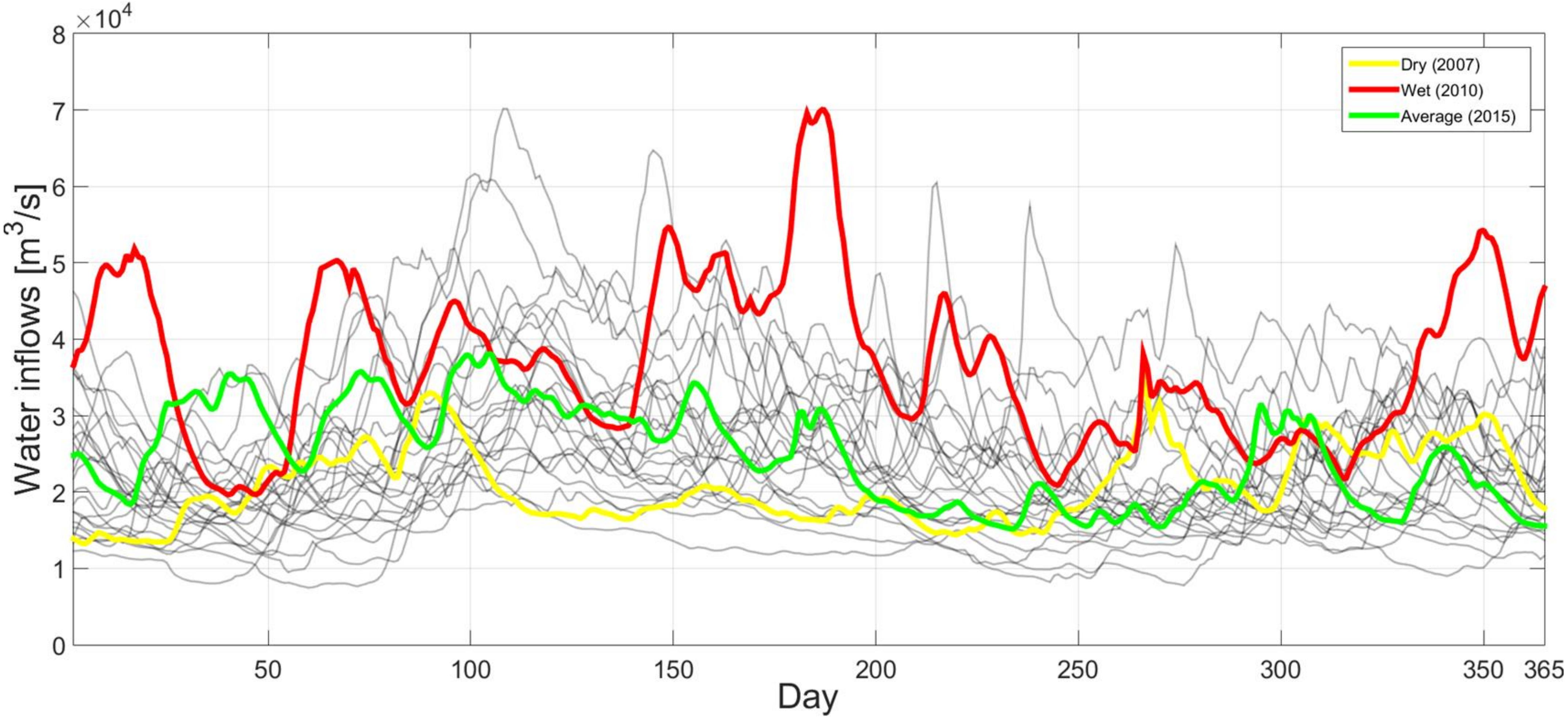

UNDERSTANDING THE ENERGY BALANCE
UNDERSTANDING THE WATER BALANCE-QUALITY
UNDERSTANDING 'CLIMATE VARIABILITY'
UNDERSTANDING 'FOOD SECURITY'
UNDERSTANDING ECOSYSTEMS
Understand. the WEFE Interactions Analysis
Identification Collaboration & Points - Interest
NEXUS ASSESMENT
Scenario Development
Strategic Framework for WEFE Nexus Security Development
RESPONSE
Investment Plans and Dev. Measures
NEXUS POLICY DIALOGUE

LISFLOOD model



P = precipitation; Int = interception; EW_{int} = evaporation of intercepted water; D_{int} = leaf drainage; ES_a = evaporation from soil surface; T_a = transpiration (water uptake by plant roots); INF_{act} = infiltration; R_s = surface runoff; $D_{1,2}$ = drainage from top- to subsoil; $D_{2,gw}$ = drainage from subsoil to upper groundwater zone; $D_{pref,gw}$ = preferential flow to upper groundwater zone; $D_{uz,lz}$ = drainage from upper- to lower groundwater zone; Q_{uz} = outflow from upper groundwater zone; Q_l = outflow from lower groundwater zone; D_{loss} = loss from lower groundwater zone.

LISFLOOD model



Energy model

GAMS +

- Developed using GAMS and Python
- Commitment and dispatch of available units on an annual basis with hourly time step
- Detailed operation of hydropower units including HROR, HDAM and HPHS
- Including water demand for non energy uses
- Including evaporation of water accumulations

Energy model

- Optimization problem minimizing system operation costs

$$\begin{aligned} SystemCost = {} & \sum_{t,u} VarCost(u) \cdot G(t,u) + \sum_{t,u} PumpingCost \cdot PUMP(t,u) + \\ & \sum_{t,u} SpillageCost \cdot SPILL(t,u) + \sum_{t,u} TransmissionCost \cdot FLOW(t,l) + \\ & \sum_{t,u} CurtailmentCost \cdot CURT(t,n) + \sum_{t,u} LostLoadCost\ LOSTLOAD(t,n) \end{aligned}$$

Energy model

- Market clearing equation

$$\sum_{u\in U(n)} G(t,u) + \sum_{l\in L(n)} FLOW(t,l) = Demand(t,n) + \sum_{u\in PUMP(n)} PUMP(t,u) + CURT(t,n) - LOSTLOAD(t,n)$$

- Hydropower generation (HDAM and HPHS)

$$G(t,u) = eta\_turb(u) \cdot DIS(t,u) \cdot NominalHead \cdot \rho \cdot g$$

Energy model

- Accumulation water balance

$$V(t,u) - V(t-1,u) = (Resources(t,u) - Evaporation(t,u) + UPSTREAM(t,u) + CH(t,u) - DIS(t,u) - SPILL(t,u) - DemandW(t,u))$$

- HPHS operation

$$PUMP(t,u) = CH(t,u) \cdot NominalHead(u) \cdot \frac{1}{eta\_pump} \cdot \rho \cdot g$$

Scenarios

- Analysis was made for 3 different scenarios
  - Reference scenario (S1) (2019)
  - Moderate energy transition scenario (S2) (2030, 2050)
  - Fast energy transition scenario (S3) (2030, 2050)
- For each scenario, wet, average and dry hydrology conditions were assessed

Reference scenario (S1)

Hydrological conditions	Hydropower generation [GWh]	Historical data [GWh]	Difference [GWh]	Difference [%]
Average year	6,438	6,767	-329	-4.86
Wet year	9,250	9,068	-182	2.01
Dry year	4,432	4,577	-145	-3.17

Moderate energy transition (S2) - 2030

Hydrological conditions	Hydropower generation [GWh]	Wind generation [GWh]	Solar generation [GWh]	Hydropower reference [GWh]
Average year	7,023	2,122	1,024	6,438
Wet year	10,089	1,854	928	9,250
Dry year	5,287	1,998	1,283	4,432

Moderate energy transition (S2) - 2050

Hydrological conditions	Hydropower generation [GWh]	Wind generation [GWh]	Solar generation [GWh]	Hydropower reference [GWh]
Average year	9,281	4,366	3,623	6,438
Wet year	10,728	3,778	3,398	9,250
Dry year	8,763	4,232	4,786	4,432

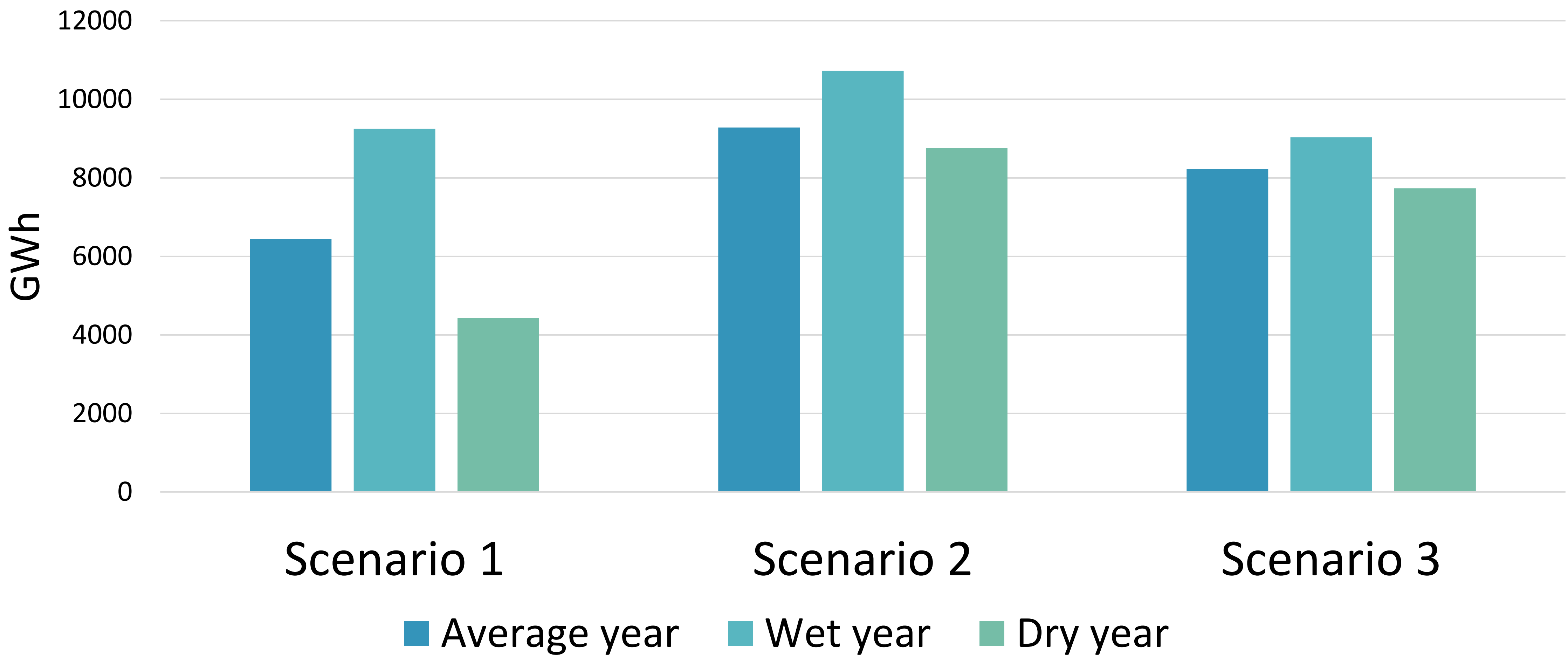
Fast energy transition (S3) - 2030

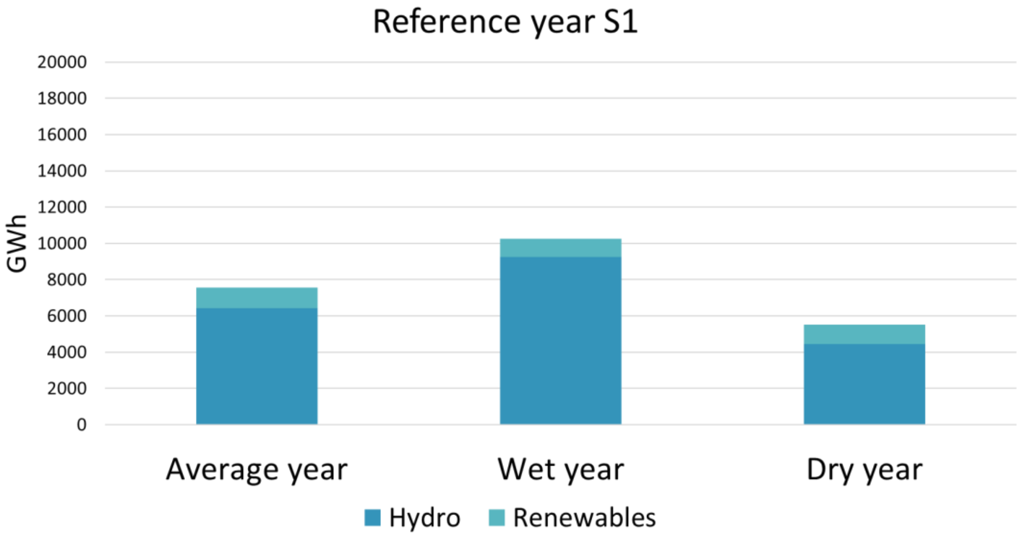
Hydrological conditions	Hydropower generation [GWh]	Wind generation [GWh]	Solar generation [GWh]	Hydropower reference [GWh]
Average year	7,328	2,632	1,238	6,438
Wet year	11,423	2,389	1,146	9,250
Dry year	5,823	2,482	1,423	4,432

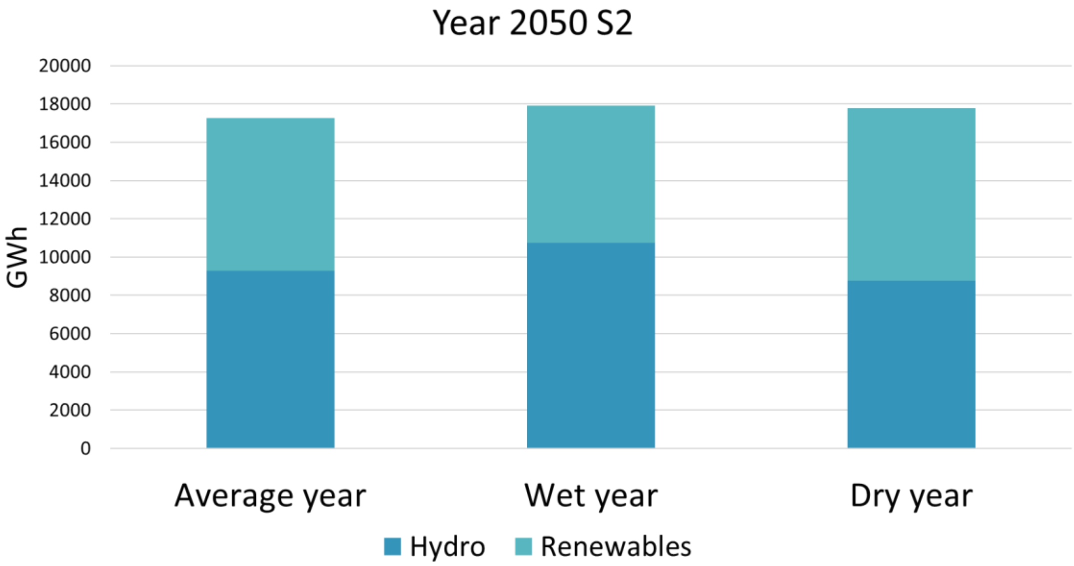
Fast energy transition (S3) - 2050

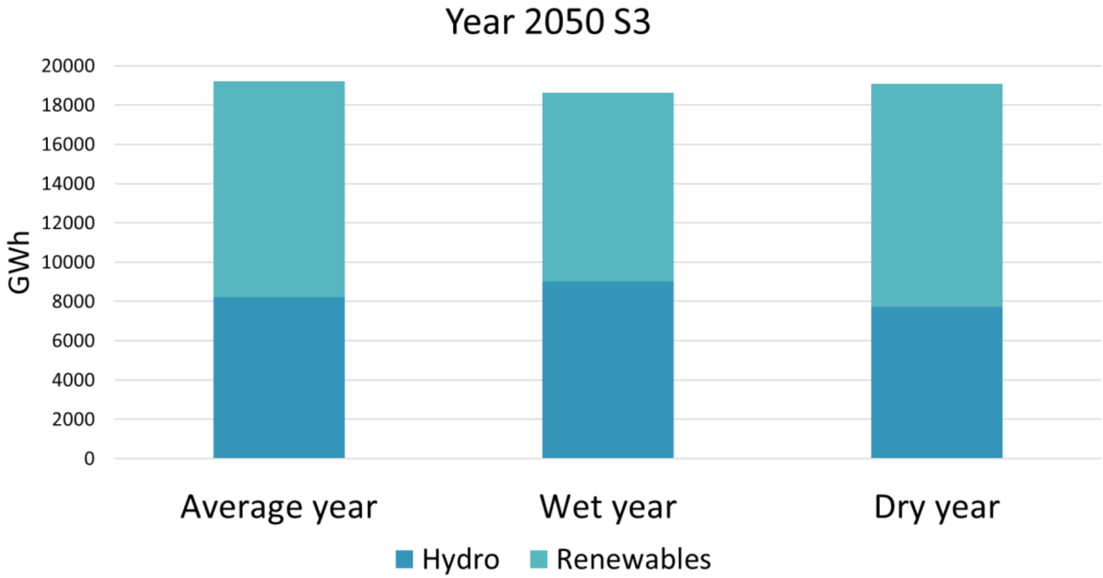
Hydrological conditions	Hydropower generation [GWh]	Wind generation [GWh]	Solar generation [GWh]	Hydropower reference [GWh]
Average year	8,220	6,483	4,520	6,438
Wet year	9,032	5,572	4,029	9,250
Dry year	7,732	5,924	5,432	4,432

Hydropower generation for year 2050




Reference year S1
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
GWh
Average year
Wet year
Dry year
Hydro
Renewables


Year 2050 S2
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
GWh
Average year
Wet year
Dry year
Hydro
Renewables


Year 2050 S3
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
GWh
Average year
Wet year
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